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FATIGUE OF LAMINATED WOOD BEAMS

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Most structures of wood are subjected to static loads but some are also subjected to dynamic loads. It is therefore of great importance to know the dynamic and the fatigue properties of wood, properties which have traditionally been ignored to some extent. Among the factors influencing the fatigue properties of wood are: the nature of the load acting on the structure, the load combinations, the type of wood, moisture content, temperature and so on.

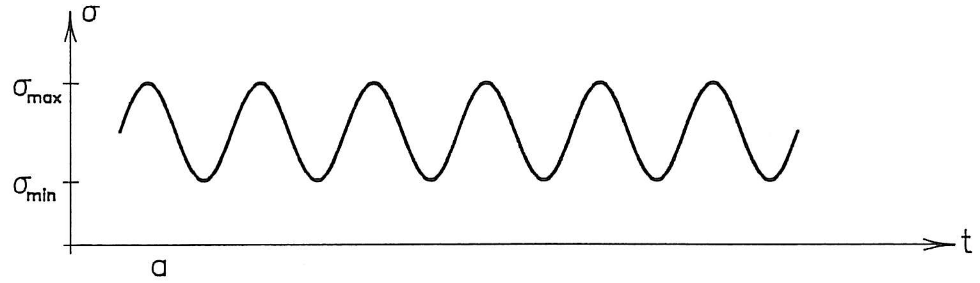
This paper describes a series of tests made with laminated wood beams with different angles between the beam axis and the fibre direction for the laminations.

INTRODUCTION

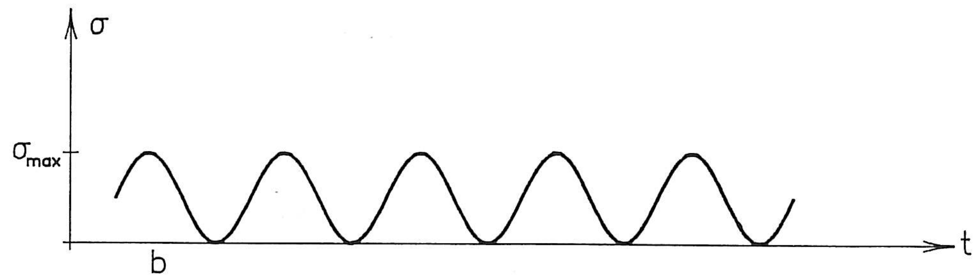
Fatigue is here defined as the progressive damage and failure that occur when a structure or a part of a structure is subjected to vibrational loads of a magnitude smaller than that corresponding to the static strength. Static strength means the strength measured in a test with a slowly increasing load, a test of a few minutes duration. Quite often the experiments resulting in fatigue are performed with *harmonic loading* where the load, stress or strain, vary with time as shown in figure 1.

For this type of loading 3 factors are of importance:

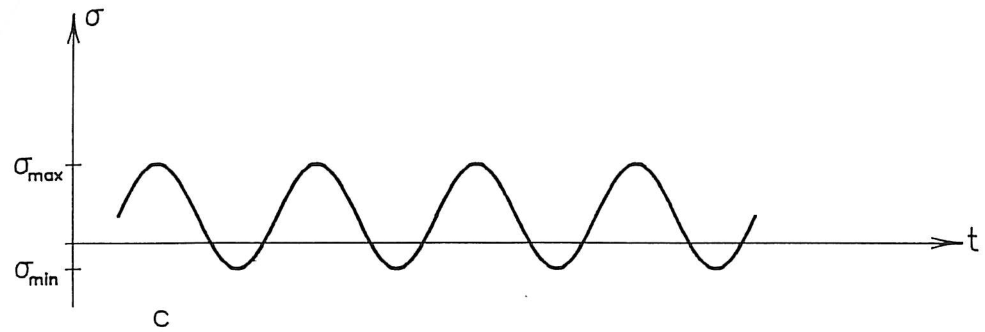
- The R-ratio defined as the ratio between the minimum stress (strain) and the maximum stress (strain). Negative values of R correspond to the so-called "reversed loading" and positive values of R to "repeated loading".
- The average value of the stress (strain).
- The frequency and therefore also the total loading time from the start of the experiment until failure. The total loading time is important since wood is a material with time dependent properties.



a. $R > 0$. "Repeated loading".



b. $R = 0$.



c. $R < 0$. "Reversed loading".

Figure 1

The most used (and most simple) method to determine the fatigue properties of a given material or structure is to determine the so-called $S-N$-diagram by experiments. The $S-N$-diagram is determined with the load varying harmonically within a given load range (or displacement range) and fixed frequency. The parameter S is for example the stress range for a simple tension experiment and N is the number of cycles to produce failure.

For a number of different specimens loaded to different maximum stresses several values of stress range and the number of cycles that produces failure can be determined. Normally N is plotted as the abscissa in logarithmic scale and S (the stress range) as ordinate (sometimes also in logarithmic scale). S is often normalized with respect to the static strength. As the magnitude of the stress range decreases the number of cycles to failure increases. Figure 2 shows examples of $S-N$-diagrams for mild steel, aluminium, concrete and wood. (Only in broad outline without details).

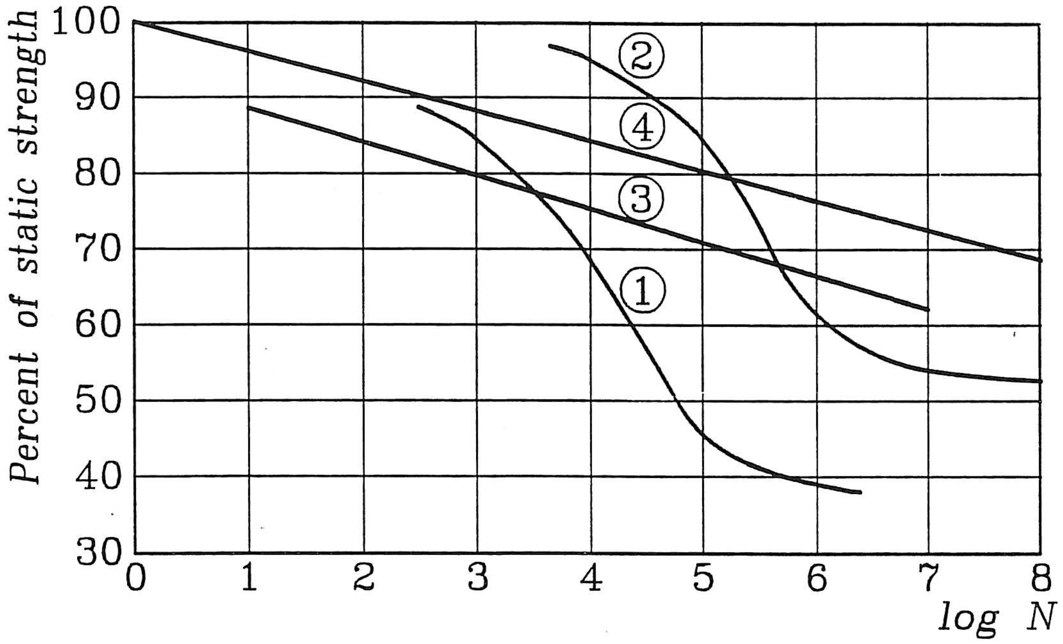


Figure 2. $S-N$-diagrams for 1 mild steel, see (1), 2 aluminium alloy 61S-T6, see (1) 3 concrete, see (2) and 4 wood, see (3).

The purpose of the experiments described in this paper is to obtain some knowledge of the influence of an angle between the fibre direction and the beam axis in four point bending of laminated wood beams.

The tests comprise a total of 258 beams which can be roughly placed in three groups. In one group we have beams with laminas and thus fibres parallel with the beam axis. In another group the laminas are inclined with respect to the beam axis, three different angles of inclination being used. The beams in this group may be further characterized as either unreinforced or reinforced in the tension side of the beam. In the third group are beams made of another material than spruce and beams with plain scarfs in the lamina in the tension side.

206 beams were tested in repeated loading with R varying from 0.12 to 0.5, and 52 beams were tested in reversed loading with $R = -1$.

EXPERIMENTAL INVESTIGATION

At the Department of Building Technology, University of Aalborg, Denmark, some test series of laminated wood beams have been carried out. Some results from these tests are reported here.

Test arrangement and test beams

A photo of the test arrangement is shown in figure 3.

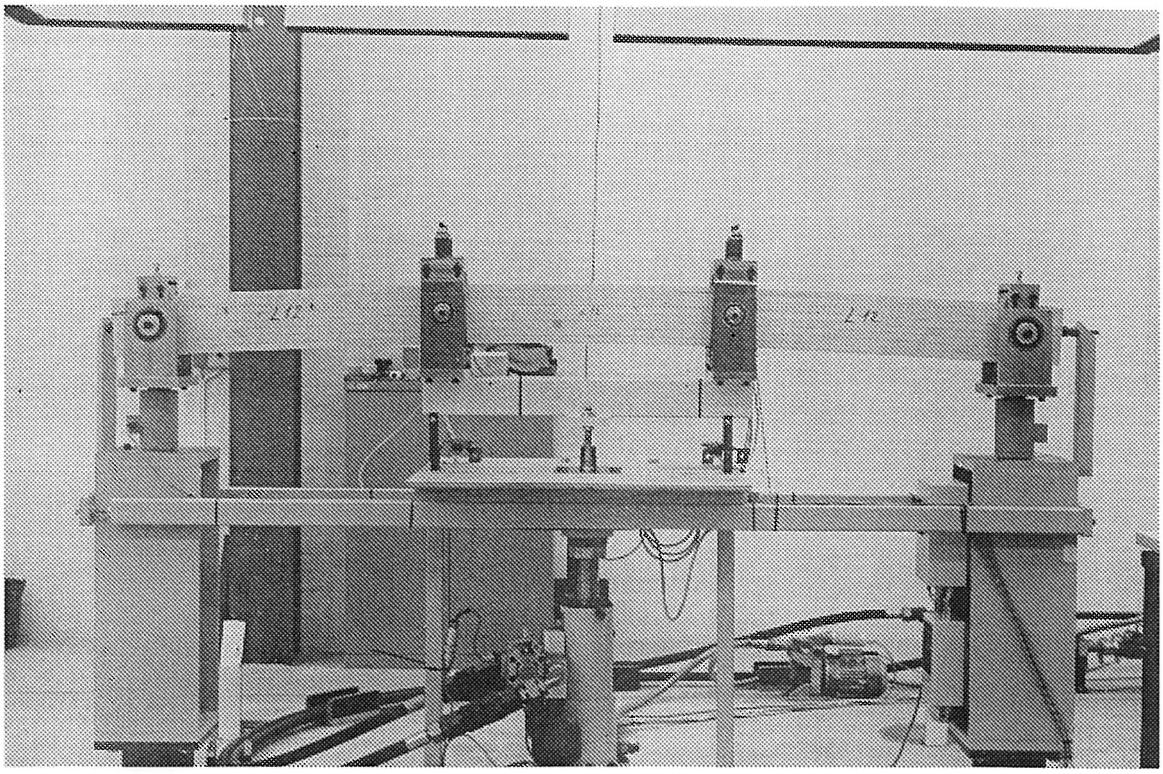


Figure 3. Test arrangement and test beam.

The test rig is designed for four point bending of simply supported laminated wood beams. The actuator is a 63 kN Schenck actuator connected to a Schenck servo-hydraulic testing system. The distance between the end supports is 2 m and the load from the actuator acts in the 1/3 points. These tests were all carried out as harmonically constant amplitude displacement - tests driven at a frequency of 10 Hz. In the first part of the investigation (206 beams) only one-sided loading was applied (the so-called repeated loading) which means that there always is tension in the lower half part of the beam and compression in the upper half part. Constant amplitude displacement test means that the force from the actuator will decrease as the fatigue process proceeds. The cross section of the laminated beams is $w \times h = 60 \times 120$ mm consisting of 6 layers. The wood material was nordic spruce and the moisture content was approx. 12%.

The minimum value of the deflection was chosen to 3 mm and the maximum displacement varied for the different tests.

During the test the constant displacement range was controlled by measuring the displacement every 2 minutes as well as the force range. This was done with an HBM data acquisition system UHM 100 combined with an HP 9826 computer.

The test was stopped at break down of the beam or when the minimum value of the force reached a chosen limit (approx. 1 kN) or when approx. 2 million cycles were reached.

In the second part of the investigation (52 beams) reversed loading was applied. (R = –1).

Before the fatigue test was started a usual load-deflection curve was determined and if possible the same was done after the fatigue process.

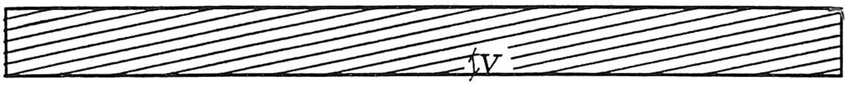
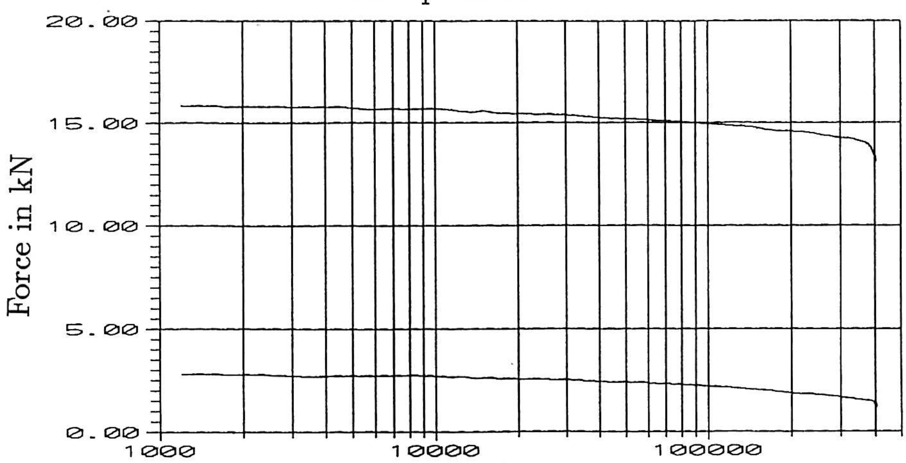


Figure 4. Sketch of a test beam.

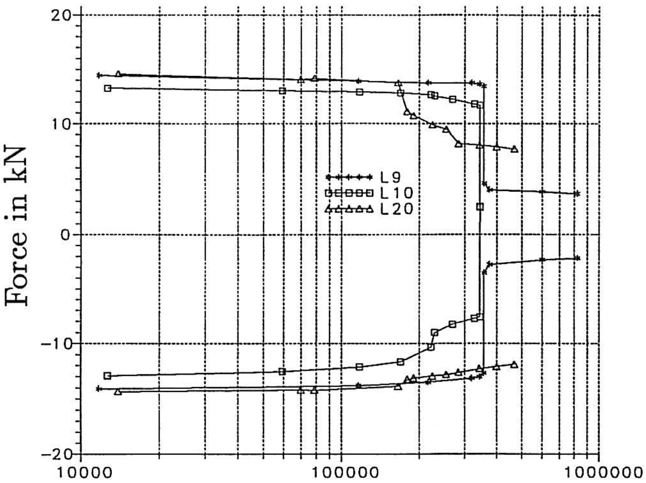
Figure 4 shows a sketch of a test beam. The angle V has the following values: 0°, 3° (1:20), 6° (1:10) and 12° (1:5)

MAIN RESULTS

Examples of variation of maximum and minimum force needed to maintain a constant displacement



a)



b)

Figure 5. Variation of maximum and minimum force during the test.

amplitude is shown in figure 5.a for repeated loading and in figure 5.b for reversed loading. Gradual decrease of force, sudden drop to a lower level or sudden failure occur in beams under both loading conditions.

The decrease in stiffness is apparent from the load-deflection curves in figure 6.

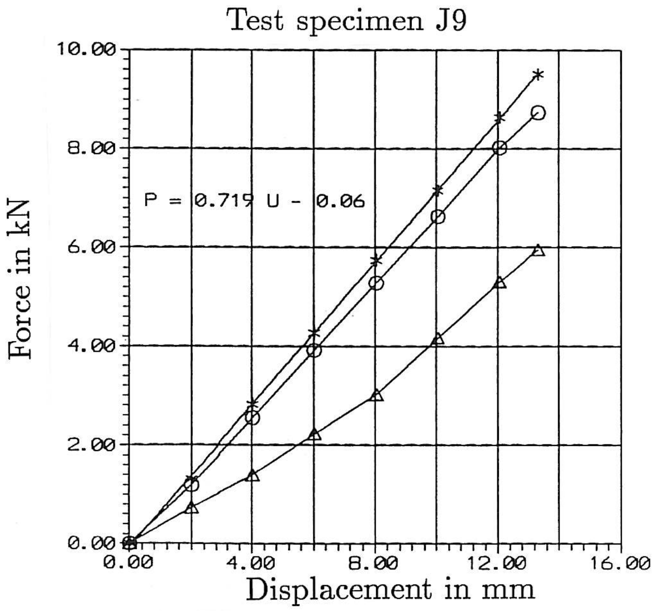


Figure 6. Load-deflection curve before test (x) after 405,000 cycles (o) and after 443,000 cycles (Δ).

In some instances the beams were completely undamaged and had the same stiffness after 2,000,000 cycles as before testing.

The two most common types of failure: the compression rupture in the upper part of the beam (repeated loading) or a tension rupture where the crack is parallel with the fibres, are shown in figure 7.

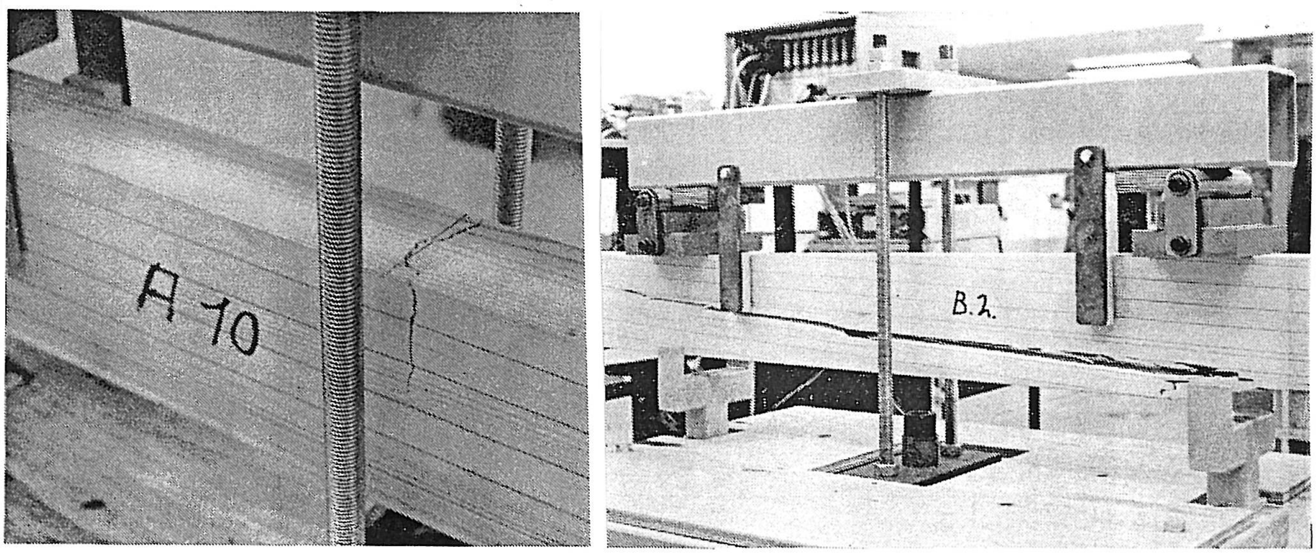


Figure 7. Failure types.

The influence of a change in angle between the beam axis and the fibre direction is shown in figure 8. The inclinations are 0° ~ series A, 3° ~ series B, 6° ~ series C and 12° ~ series D. The decrease in fatigue strength is obvious.

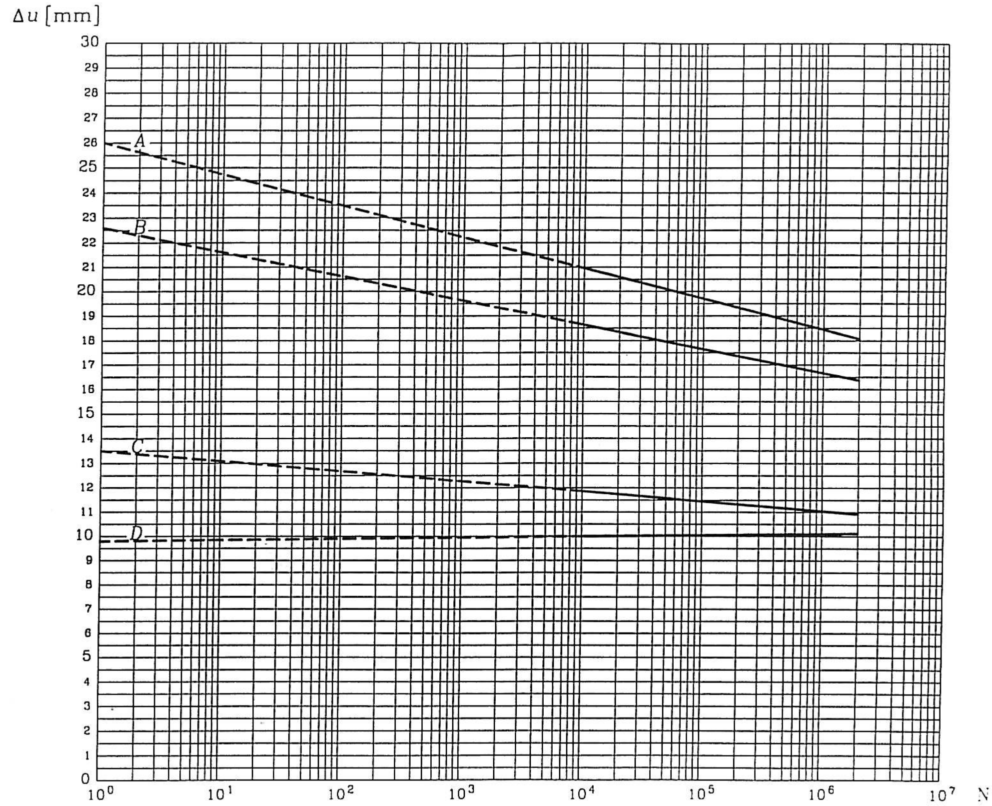


Figure 8. $S - N$−curves for series A, B, C and D.

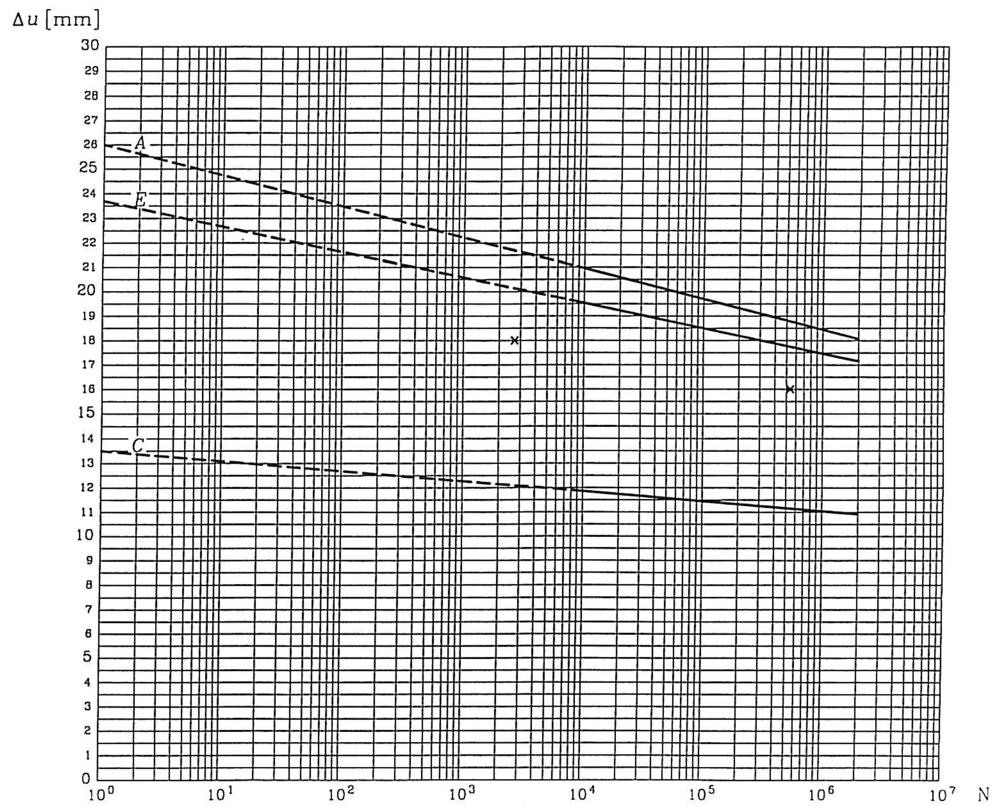


Figure 9. $S - N$−curves for series A, C and E.

The effect of a reinforcement is shown in figure 9. The beams in series E (V ~ 6°) are supplied with a 5 mm lamina with fibres parallel with the beam axis in the tension side. They have a fatigue strength only slightly lower than the beams in series A (V ~ 0°). The two x's indicate results for two beams reinforced with a 1 mm layer of epoxy.

While figure 8 shows $S-N-$curves for beams in repeated loading the $S-N-$curves in figure 10 are for beams in reversed loading (L ~ 0°, M ~ 6°, N ~ 12°).

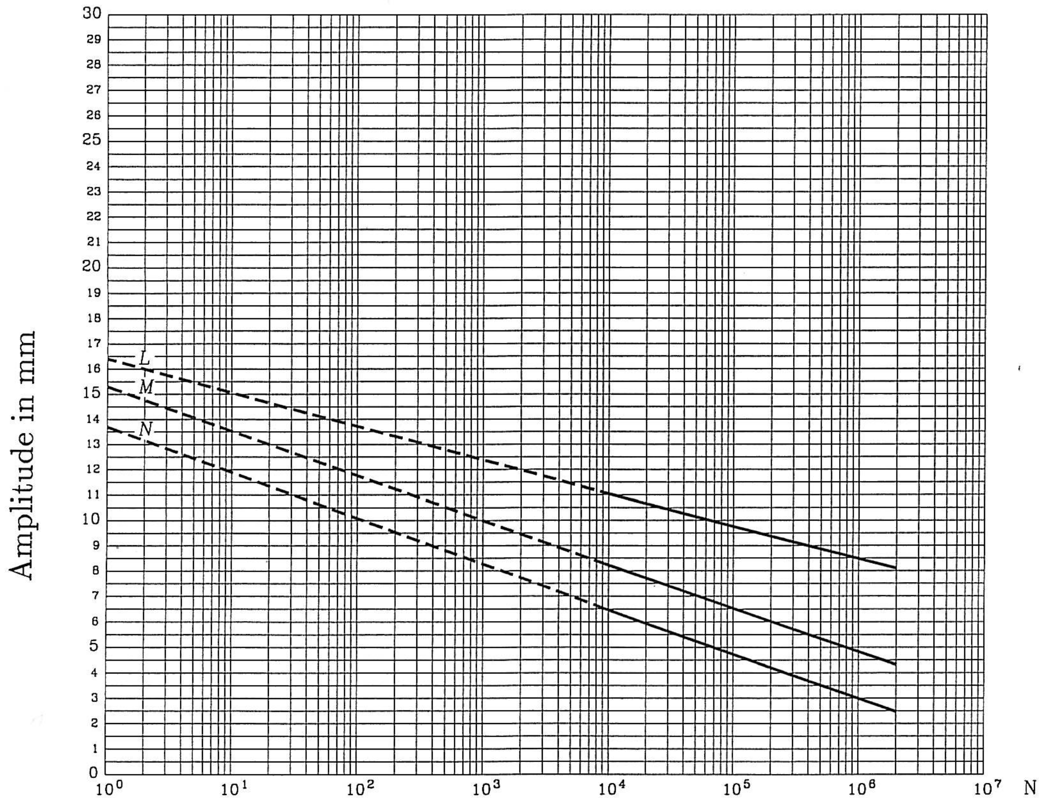


Figure 10. $S-N-$curves for series L, M and N.

The complete investigation is reported in reference (4).

ACKNOWLEDGEMENTS

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